Extended MHD Simulations of D3D 86144[1]

T.A. Gianakon

D.D. Schnack

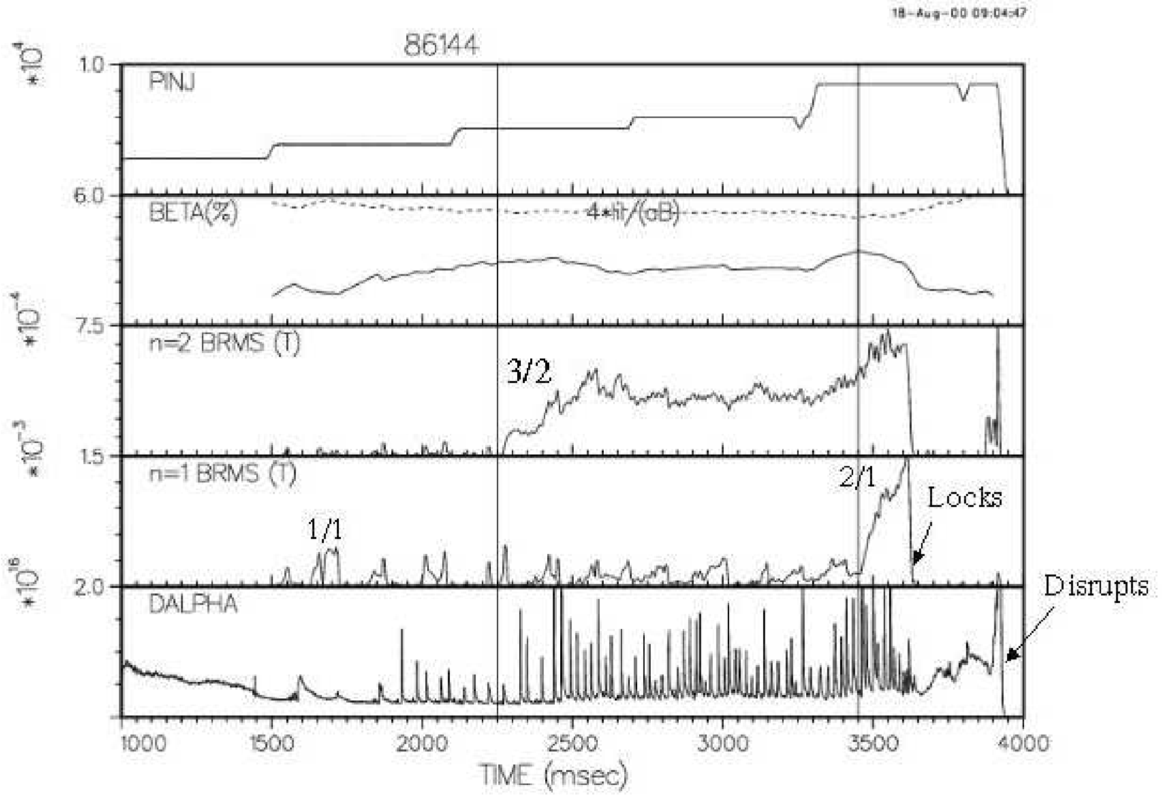
28 October 2001

Long Beach, CA

[1] Research supported by U. S. DoE

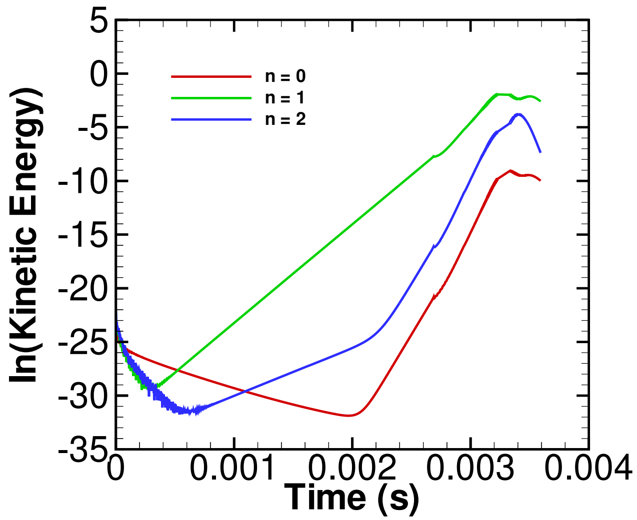
Modern Tokamak Discharges Have Rich Magnetic Behavior

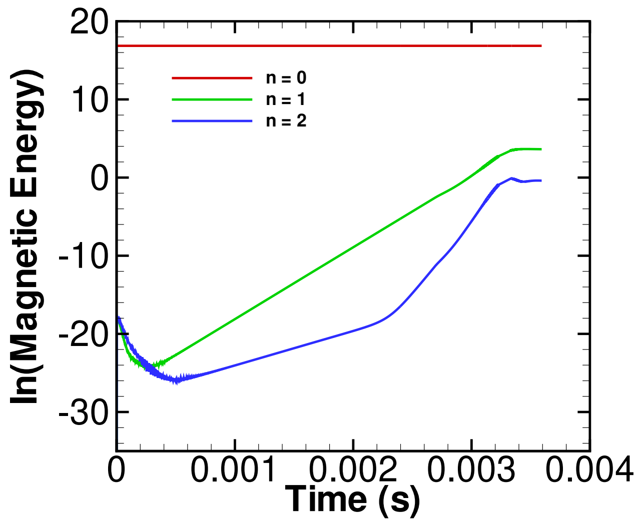
NIMROD



Courtesy of R. LaHaye, General Atomics

Both n=1 and n=2 are unstable. Mode coupling dominates n=2.

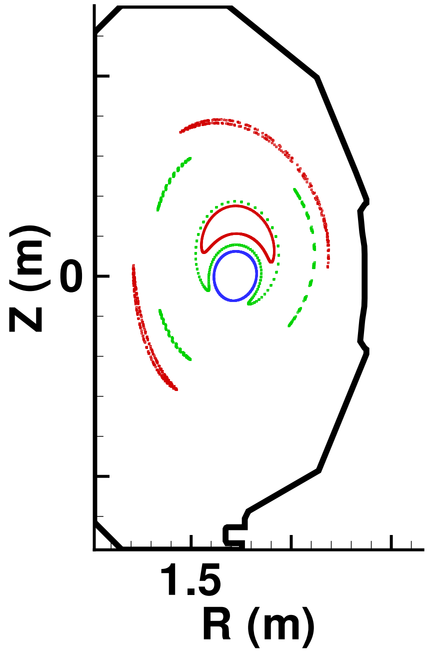


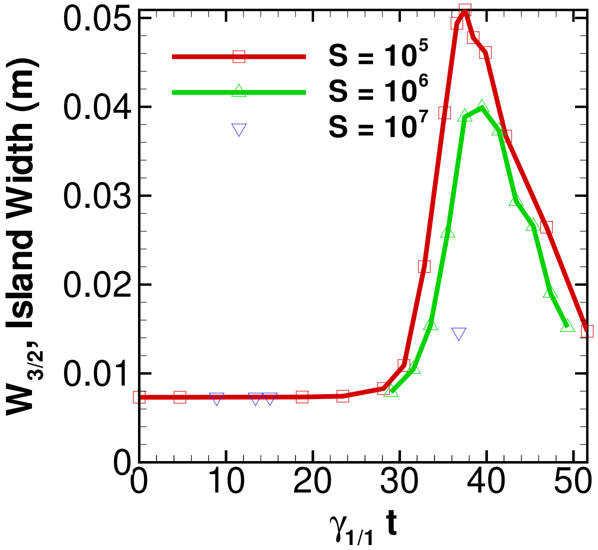


- **Change in n=2 slope is nonlinear coupling 1/1 to 2/2.**
- **NIMROD growth rate is $\gamma = 4.58(10^3)(s^{-1})$ at $S = 10^7$ and $P_m = 1000$.**
- **Experimental measurement from a fit of the Mirnov coils gives $\gamma = 1.68(10^4)(s^{-1})$.**

Secondary islands form, but too small to explain 3/2.

- Secondary island formed by nonlinear couplings.
- Secondarv island width is reduced with decrease in resistivity (S increases).





Extended MHD seeks numerically tractable forms to close MHD equations.

- Resistive MHD is incomplete.

  A 3/2 tearing instability is observed in the experiment, but with resistive MHD the island width is too small.

- The $|\boldsymbol{B}|$ variations along a magnetic field lead to particle trapping effects.
- Particle trapping cause neoclassical effects:

  Damping of poloidal flows.

  Neoclassical enhancement of the polarization current.

  Generation of bootstrap currents.

- A simplified viscous stress tensor captures most neoclassical effects

$$\nabla \cdot \vec{\vec{\Pi}}_\alpha = m_\alpha n_\alpha \mu_\alpha \langle B_0^2 \rangle \frac{\vec{v}_\alpha \cdot \nabla\theta}{(\vec{B}_0 \cdot \nabla\theta)^2} \nabla\theta,$$

  where α indicates electrons and ions, and μ_α is a flow damping rate.

- Extensive testing of more complete closures completed to verify the simple form.[2]

[2] T.A. Gianakon, S.E. Kruger, C.C. Hegna, Physics of Plasmas, **9** January 2002.

The perturbed bootstrap current can cause instability.

- Pressure flattening causes a perturbed bootstrap current.

  Anisotropic heat diffusion about an island causes $\nabla P \longrightarrow 0$.

  A helical hole in the bootstrap current is formed.

  The hole in the perturbed bootstrap current causes island growth.

- Physics captured by a simple Rutherford island evolution equation.

$$\frac{k_0}{\eta^*}\frac{dW}{dt} = \Delta' + \frac{W_{nc}}{W}\frac{W^2}{W^2 + W_d^2}$$

  The Δ' is nominally negative, (standard tearing is positive.)

  The first half of the second term is the bootstrap current.

  The second half is the correction for anisotropic heat diffusion.

- The anisotropic heat diffusion causes a nonlinear threshold for instability.

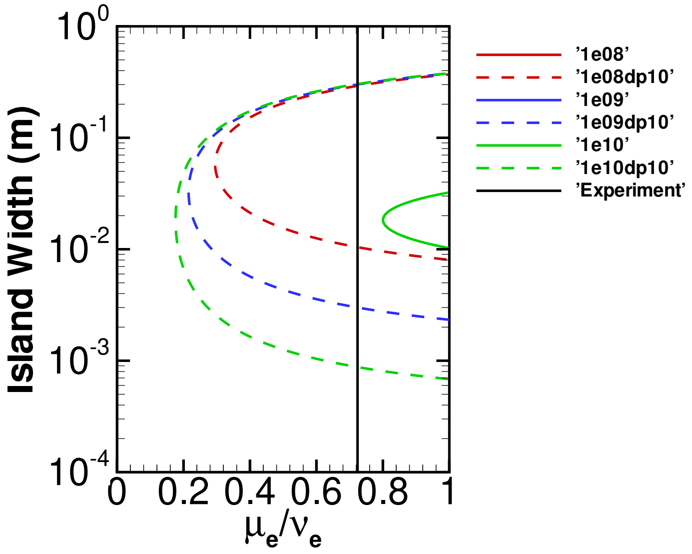
  For $W < W_d$, no pressure flattening occurs.

  For $W > W_d$, pressure flattening occurs.

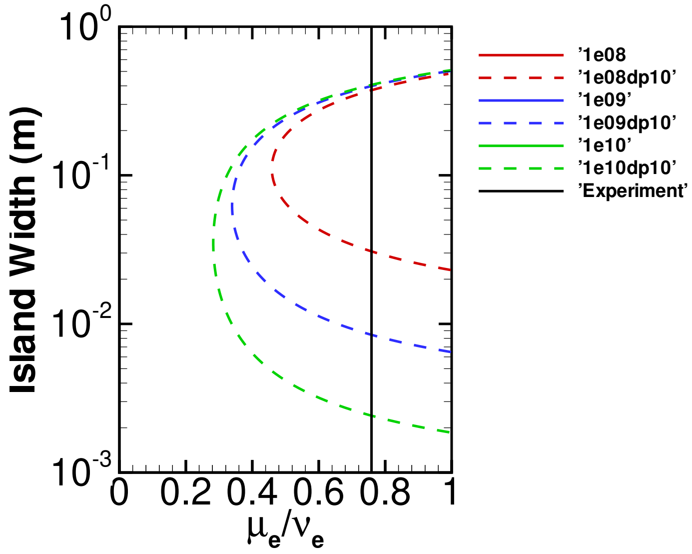
- The formation of secondary islands is necessary to seed this instability, the neoclassical tearing mode (NTM).

Seed islands cross NTM stability boundaries for 86144.

The 3/2 stability boundaries.

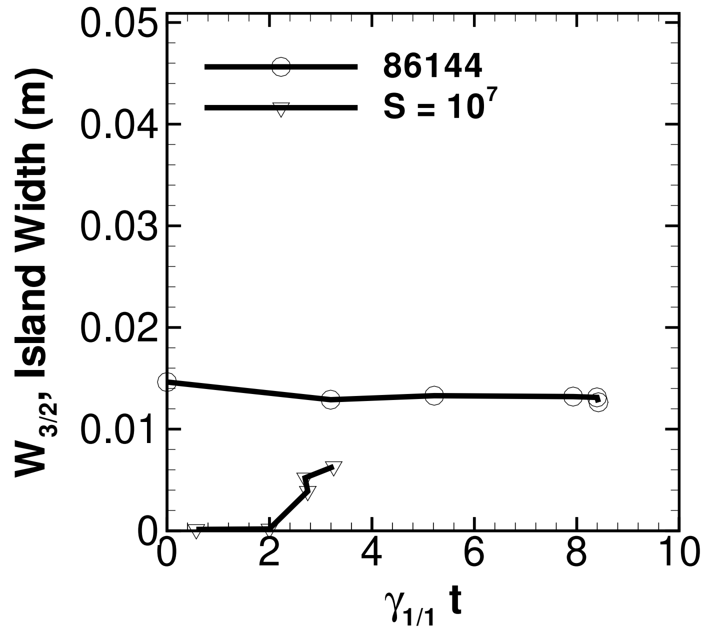


The 2/1 stability boundaries.



- **Uncertainty in both $\chi_{||}/\chi_{\perp}$ and Δ' exist.**
- **The 2/1 is not neoclassically unstable—consistent with experiment.**
- **The 3/2 is potentially neoclassically unstable.**

Extended MHD indicates 86144 has growth of 3/2.



Summary

- **Nonlinear simulations with** *NIMROD* **of DIIID Shot 86144.02250 illustrate a rich array of MHD and extended MHD effects.**

- **Growth and saturation of an internal kink can be identified.**

- **Secondary island formation from the internal kink is modeled.**

- **Growth of neoclassical tearing modes.**